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Feasibility study of wide band laser surface treatment

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Abstract

In the field of materials processing, the laser techniques employed for surface modification have contributed greatly to the development of materials with specific features. However, despite the advantages of laser surface treatment, its application is limited because the process is slower than other techniques. This paper presents a feasibility study of wide band laser treatment, a method that, by enlarging the scanning width, increases the efficiency in comparison to several tracks of conventional laser surface treatment. Experimental tests have shown that wide band laser treatments with this experimental system can achieve processing rates 10 times higher than conventional devices.

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1. Motivation / State of the Art

In recent years there is an increasing need of advanced materials that must withstand extreme conditions. Therefore, these materials might show features, such as high specific strength or high hardness, but at reduced costs. Usually, these properties are required only on the material surface, keeping the core part unaltered. Surface treatments can provide a common material with the needed surface characteristics, either by changing its surface structure, such as a hardening, or changing its composition by means of another material contribution.

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Due to the properties of the laser radiation, laser surface treatment has a great number of important advantages over other techniques: reduced heat affected zone, low distortion and high accuracy [1,2]. Laser surface treatments comprise hardening, quenching, cladding, surface alloying, or laser blasting, among others. However, despite the advantages of laser surface treatments, their implementation to process large areas is limited. Spot size is reduced and, as a result, to cover a large area many passes are needed, consequently, the process is slower than other techniques. Nowadays, the availability of powerful laser sources provides higher laser power than that employed by conventional laser assisted surface treatments. Some authors have already worked to solve this problem and to make the most of the accessible laser power. Pekkarinen et al. [3] studied the use of scanning optics to produce a more extensive laser cladding than with the conventional method. Jae-Do Kim et al. [4] managed to increase the width of scanning using a pyramid polygon mirror. Stan Ream [5] introduced a new polygon scanner for laser paint stripping and coating removal of large areas.

In the present study we report the design and development of a new prototype of extensive surface treatment laser device that overcomes the limitations of the laser surface treatment. The method and system were tested for three different laser assisted surface treatments: laser cladding, laser blasting, and laser hardening; whose productivities are prone to be improved by an extension of the processed area [6-10].

2. Experimental

The experiments were carried out using two high power laser sources, a 3.5 kW CO₂ slab laser (Rofin, model DC 035, $\lambda = 10600$ nm), the laser mode being a TEM₀₀; and a 3.0 kW multimode fiber laser (IPG, YLS3000, $\lambda = 1070$ nm). Obviously, each laser source was operated with its specific optic system. With the aim of increasing the size of the spot, we developed a new experimental device based on a scanning system which delivers a rectangular spot. The system scans in only one direction; therefore, the dimension of the smaller side can be adjusted between 1 and 10 mm by means of a 500 mm focal length. The larger size can be varied between 50 and 150 mm. Figure 1 shows two images of a targeting laser beam ($\lambda = 532$ nm) used in such operating system. The sample movement relative to the laser working head was governed by a CNC machine (LANTEC 2000).

Laser cladding was tested by feeding and injecting tin powder on the rectangular molten pool created by the laser beam on a stainless steel substrate. In order to establish the processing window for laser cladding in such conditions, the laser power and the processing speed (transversal to the larger side of the spot shown in Figure 1.b) were modified between 1500 and 3500 W, and between 5 and 25 mm/s, respectively. A specific powder injection nozzle was designed and fabricated to produce a powder stream with a rectangular profile matching with the laser irradiated area.

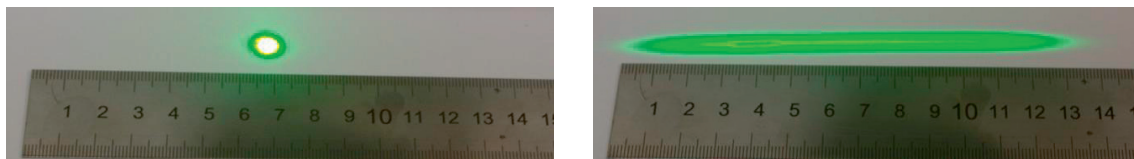


Fig. 1. (a) Scanning system shutdown; (b) Scanning system in operation.

The objective of laser blasting applied to natural stones and ceramics is to change the surface roughness for nonslip or aesthetic applications. Pink granite tiles with thicknesses between 5 to 20 mm were exposed to CO₂ laser radiation in order to modify the surface roughness and related surface appearance. The surface roughness

was measured by means of a surface roughness meter (TESA, Rugosurf 10G) prior and after laser blasting.

Surface hardening. The substrates used for the experiments were AISI 1045 flat plates with 40 mm x 60 mm area, and 10 mm of thickness. The alloying elements are C(0.42–0.50%), Mn(0.60–0.90%), Si(0.15–0.40%), S(0.050% max) and P(0.040% max). The typical value of Vickers hardness of this steel is 165–255 HV100. In order to approach the processing conditions of massive components, with important heat conduction towards the inner volume, a 25° compressed air stream was directed to the plate surface opposed to the hardened surface. Moreover, a pyrometer (model KTR 1475, Maurer) was positioned by a motorized stage in order to measure only the radiation emitted by the heated surface of the sample. The surface of the samples after the heat treatment was characterized through optical and electronic microscopy. Samples were cut into pieces of dimension 25 mm x 25 mm. Subsequently, they were grounded, polished and etched by means of the Nital's reagent in order to reveal the microstructure. After polishing and etching, samples were characterized through a stereoscopic binocular microscope Nikon SMZ-10A connected to a PC to record the images and by means of a scanning electronic microscope (Philips XL 30). Finally, the Vickers hardness of the treated samples was measured.

3. Results and Discussion

The scanning width can be adjusted depending on the distance at which the substrate is positioned respect to the scanning system. To test the prototype, we started performing several tests of laser cladding with CO₂ laser irradiation. Tin powder was used as precursor material and stainless steel plates were used as substrate. This device allowed to produce clad tracks up to 100 mm wide. Fig. 2.a shows an image of a stainless steel sample being coated with a tin layer by wide-band laser cladding. The process optimization results are summarized in the graph shown in Fig. 2.b; the main indicator chosen to categorize the result of each combination of processing parameters was the quality of the interface between the coating and substrate, observed at samples cross-section. It is noticed that increasing the laser power enhances the soundness of the coatings and the adhesion at interface; while increments of processing speed reduce the average energy density at the surface, thus penalizing the coating continuity at interface. As a result, the experimental system is competitive at high laser power. On the contrary, at low power no benefits are obtained in comparison with conventional systems. This behavior was expected, and endorses that the wide band laser cladding will show all its potential when applied with higher laser power. Laser powers between 5 to 8 kW will allow to increase the processing speed and thus the productivity of the technique, also when cladding coatings of higher melting point.

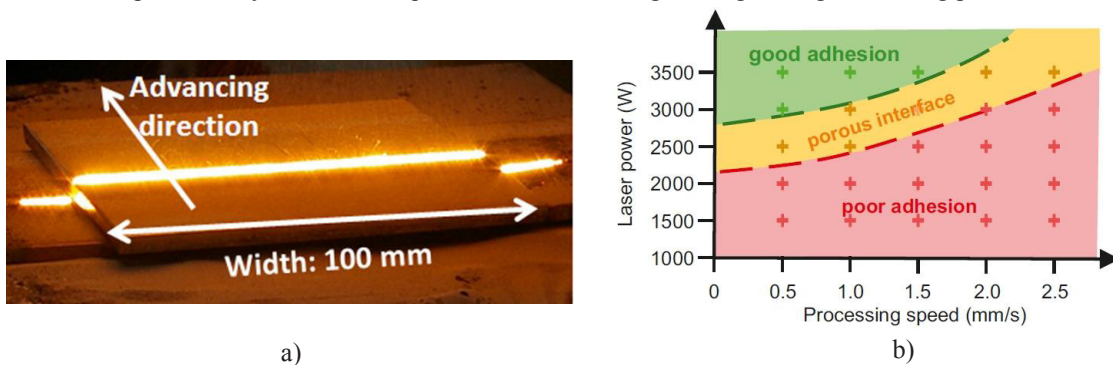


Fig. 2. (a) Rectangular laser spot on substrate during laser cladding. (b) Laser cladding working window as a function of the coating-substrate interface quality.

Various experimental tests were performed of granite wide band laser blasting with CO₂ laser irradiation. Fig. 3.a shows an image of a pink granite sample processed with this new system. Roughness charts of untreated granite and wide-band laser treated granite are shown in Fig. 3.b. Experimental tests allow to conclude that this device can perform different surface treatments ten times faster, in terms of processed surface per unit time, in comparison to conventional laser devices. This fact is a definitive milestone in the development of the laser blasting technique. Previous studies demonstrated the versatile distinctive of this laser assisted technique and the reduction in noise, in generated unwanted powder, and in equipment maintenance compared to bush hammering and blowtorch flaming conventional techniques [13]. If the productivity was the remaining challenge for laser blasting, the development of powerful laser sources together with the experimental arrangement employed in this work situated this technique in a privileged position in the group of stone surface processing techniques.

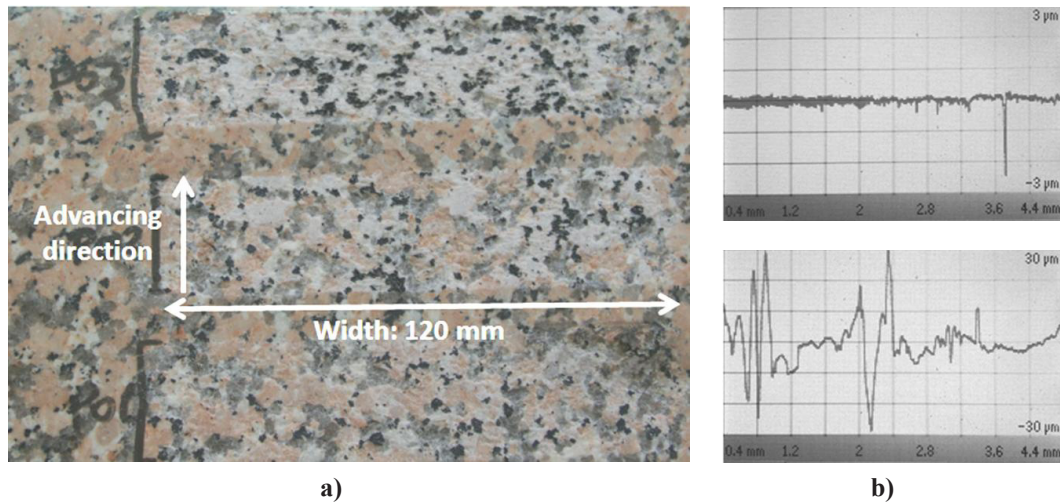


Fig. 3. Wide band laser blasting of a pink granite plate (CO₂ laser; laser power 1000W, scanning speed). (a) Laser processed areas on pink granite; (b) Top: Roughness profile of original granite surface (note scale: 3 to -3 μm). (b) Bottom: Roughness profile of laser processed granite surface (note scale: 30 to -30 μm).

Wide band laser hardening was tested by irradiating the AISI 1045 plates; hardened tracks with widths of 75mm were successfully generated on the surface. While maximum hardness values of 527 HV were obtained for very short tracks, hardening of 50 mm long tracks reduced the maximum values to 419 HV. Such reduction of maximum hardness value is attributed to the decrease of cooling speed when irradiated almost the whole plate surface. The limited heat dissipation by conduction in the small plate volume leads to a low cooling speed, as the convection dissipation induced in the opposite surface cannot simulate the effect of conduction dissipation during massive components hardening, for instance, when treating a medium size power transmission shaft [12,13]. Moreover, the small size of the plate leads to uneven cooling rates and associated hardness values. Fig. 4.a shows the appearance of hardened surface produced by only one track, and its measured hardness values are represented in Fig. 4.b. The roughness of the plates were preserved during wide band laser hardening, as observed in Fig. 5.

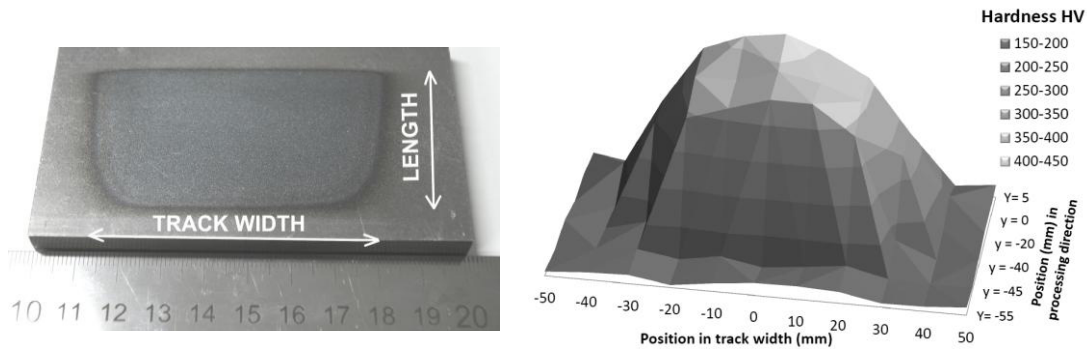


Fig. 4. Hardened surface by a single track (width 75 mm) and averaged hardness mapping.

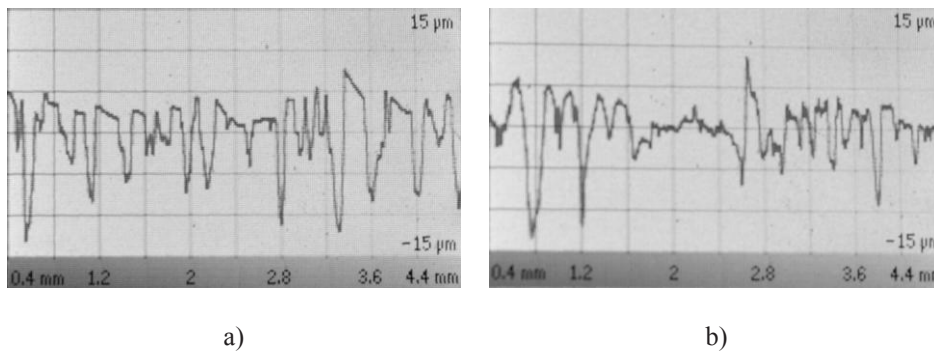


Fig. 5. Representative roughness profiles acquired on the (a) untreated surface and (b) hardened surface.

4. Conclusions

The feasibility of wide band laser surface treatment has been demonstrated for three different types of surface treatments. Laser blasting of thin granite tiles has been accomplished with processing widths of 120 mm and medium-low laser powers. The results obtained with these processing conditions allow to claim an important increase in productivity, and support the potential of wide band laser blasting to process several complete ceramic tiles at once, with just one track, when operating at high laser power values. Laser cladding of wide tracks has been observed to be feasible; however, due to higher energy requirement than the previous application, benefits of the larger beam profile are only observed when operating at high laser power. Finally, laser hardening of extended surfaces at once were produced, demonstrating the potential of wide band laser hardening to increase the rate of processed area when massive components are to be treated.

Acknowledgements

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